**BELLCOMM, INC.**
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Comparison of the Communications and Tracking Coverage Provided by Apollo Injection Ships and Land Stations - Case 320

DATE: December 28, 1967

FROM: J. P. Maloy

## ABSTRACT

This memorandum shows that an MSFN station at Tananarive can provide essentially the same communications and tracking coverage for Apollo missions as a ship located near the south-east coast of Malagasy. The principal conclusions are:

1. Tananarive can provide post-injection coverage for most first revolution injection opportunities during the time of the lunar month when the injection would occur in this area. A ship positioned at 47°E; 25°S could provide about the same coverage. Either Tananarive or a ship could provide all the coverage for second and third revolution injection opportunities in this area except for a very small region.

2. For early earth orbital coverage (first four revolutions), Tananarive and a ship located as above appear to be equally effective overall.

3. For long duration earth orbital missions, a ship could be optimally located so that it would provide better overall coverage than a fixed ground station at Tananarive.

4. A station equipped with a Comsat terminal would have an advantage in communicating with MCC-H. Three Apollo tracking ships are being equipped with Comsat terminals.



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# MEMORANDUM FOR FILE

A study was undertaken to determine the communications and tracking coverage that a proposed USB station at Tananarive would provide in lieu of placing a tracking ship in that vicinity. The examination was primarily based on two previous studies; namely, "A Study of Instrumentation Ship Requirements for the Apollo Program," dated September 14, 1963, by Bellcomm, Inc., and, "Injection Ship Positioning Technique for Apollo Lunar Missions," dated June 23, 1967, prepared by TRW, Inc., for MSC.

## Injection Coverage

The current S-IVB design limits injection opportunities to the second and third revolutions for the first lunar mission. This constraint may be removed for later lunar missions. There is no requirement for tracking of the actual injection burn, although voice and telemetry communication will be provided by the Apollo Range Instrumented Aircraft.

Ten minutes of tracking of the space vehicle is required during the first twenty minutes after injection burn cut-off to derive trajectory information for a GO/NO/GO decision.* A large region near the southern tip of Africa does not provide adequate coverage with existing land stations for a large percentage of injection opportunities. To meet the requirement that the ground communication and tracking system should not impose limitations on the time when a lunar mission may be undertaken, tracking coverage must be provided in this region.

The area enclosed by the orbital ground tracks (as shown in Figure 1) also contains, to a close approximation, the ground tracks of the translunar injection trajectories for times less than 30 minutes after injection. The coverage at 21 minutes after injection provided by the existing land stations is shown in Figure 2.

*"Trajectory Document No. 67-FMP-3, AS-504 and Subsequent Missions, Joint Reference Constraints," MSC and MSFC, March 15, 1967.

The earlier Bellcomm study indicated that a ship placed off South Africa (47°E; 25°S) almost completely fills in the existing coverage gap between ten minutes and twenty minutes after injection for all revolutions. Tananarive, as shown in Figure 3, would do essentially the same thing. This graphical presentation shows that the basic requirement of ten minutes of tracking out of the first twenty minutes after injection can almost completely be obtained by a station at Tananarive. Coverage on launch azimuths close to 72° on the first revolution, and 108° on the second and third revolution would fall short of the basic requirement but this would also be true for the ship and to almost the same extent.

A ship would have a keyhole (approximately 15°) directly overhead and hence a "blind spot" for a trajectory that would make a near overhead pass. (It may be possible that the ship could maneuver in such a manner that no coverage would be lost). From this point of view, a land station at Tananarive may have an advantage since the keyhole for such a station would be in a North-South direction and clear of any revolutions under consideration here. This can be seen in Figures 4 and 5. The keyholes in the outer coverage contour (1190 nm altitude; TLI cut-off + 600 seconds) are outside the area of ground tracks and would cause no gaps in injection coverage.

If injection during the first revolution is a possibility, a ship may be more useful due to the flexibility it can provide. As seen in Figure 3, there is a gap in coverage between Ascension and the ship (47°E; 25°S) for azimuths close to 72° on the first revolution and 108° on the third revolution. By moving the ship a trade-off can be made between these two gaps to optimize coverage for the specific mission plan. (The earlier Bellcomm study assumed that injection would not take place on the first revolution).

In the TRW study, for this portion of the lunar month, two ships were placed in the vicinity of South Africa, one to west and the second to the east. Two ships would not be necessary to provide the basic requirement of ten minutes of tracking out of the first twenty minutes after injection. Both were used in the belief that both would be available and, hence, more coverage could be provided than the basic requirement called for. Application of graphical methods from the TRW study has indicated that the same position (47°E; 25°S) is a near-optimum one for deploying a single ship to meet the minimum requirement for all launch opportunities (i.e., the two studies reached the same conclusion with regard to ship positioning in this area.)

This one ship position suggested lies to the southeast of the Island of Malagasy. Tananarive is located near the middle of this island (47°E; 19S). Figures 4 and 5 indicate what coverage could be provided by a station located at Tananarive (TAN). Since the "TLI cut-off + 600 seconds" contour for TAN overlaps the one for Ascension (ASC) for all launch azimuths on the second and third revolution, it can be concluded that the basic requirement of ten continuous minutes of tracking can be met. To quote the TRW study on this: The figures show "that in the region of the ground traces, the station visibility contours overlap for altitudes above 1190 nautical miles. This altitude corresponds to the altitude that is achieved ten minutes after the TLI cut-off. Since the ground trace of the first twenty minutes of the translunar coast closely approximates the 100 nautical mile parking orbit trace, the contours will also overlap for the coast phase. The overlapping of the contours implies that regardless of the position of TLI cut-off point, the spacecraft will generally be visible ten minutes after TLI cut-off and will remain visible until the end of the twenty-minute period. This satisfies the minimum coverage requirement."

An appendix to this TRW report examined the ship coverage necessary for more stringent requirements such as providing continuous coverage from TLI ignition until the end of the first ten minutes of the translunar coast for injections during the second revolution. Under these conditions, two injection ships would be required. In general, the more stringent the requirements, the more ships will be needed.

Earth Orbital Coverage

For the first three revolutions in earth orbit, Tananarive and the ship appear to be equally effective overall as shown in Figure 6 and Tables I and II. Tananarive would favor the azimuths nearer 72° whereas the ship in the location shown would provide better coverage for those launch azimuths near 108°.

A computer comparison was made of the earth orbital coverage phase of a lunar mission provided by a station at Tananarive (47°E; 19°S) with that of a ship stationed off the southeastern tip of Malagasy (47°E; 25°S) with 105 nm altitude and a minimum elevation angle of 0° from the stations to the vehicle. The figures shown in Tables I and II indicate that nearly equal coverage over the range of launch azimuths for the first four revolutions is provided by either station. The fourth revolution was included in the event of an abort situation. The gaps in coverage between stations using either the station at

Tananarive or the ship are also tabulated. All USB land stations plus one insertion ship were considered in determining these gap times. None of these gaps in either case exceed more than 1/2 revolution.

The one significant difference that should be pointed out is that the ship in this assumed location does not provide any coverage on the first revolution for launch azimuths close to 72°. Injection on the first revolution is not planned for the initial lunar mission but may be possible for later missions.

Coverage for a Long Duration Mission

For a 14-day mission with a constant 105 nm altitude and an elevation angle of 5°, a ship at the location assumed in this study would provide a greater number of contacts (86) than Tananarive (60). More contact time (344 minutes) would be acquired by the ship than the land station (239 minutes).* For other long duration missions with different trajectory parameters, a ship, due to its maneuverability, could be optimally placed prior to launch.

Ground Communication

Figure 7 shows the ground communications routes from Tananarive back to the U. S. mainland excluding Comsat facilities. These routes are combinations of HF radio, undersea cable and land lines. A ship in the vicinity of the Malagasy Republic, the island on which Tananarive is located, would have approximately the same ground communications route plus one extra HF link, so that Tananarive would be preferable over the ship exclusive of Comsat capability. However, two of the Apollo ships, the Mercury and Redstone, have already been equipped with Comsat terminals and the third, the Vanguard is presently being fitted out. The ships so equipped would have a superior communications facility since the unreliable link of HF radio would be eliminated.

Conclusions

This study compares the communications and tracking coverage provided by a ground station at Tananarive with a ship located in close proximity to the island of Malagasy. It does not compare construction and operating costs, scheduling, etc., and only to a limited degree the ground communications from a ship versus a land station.

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*"Analysis of Additional Communications Coverage that Could Be Obtained by Unified S-Band Stations at Canton Island, Kano, and Tananarive," August 30, 1966, by J. P. Maloy, TM-66-2021-10.

The following conclusions can be made from the data presented:

1. Tananarive can provide post-injection coverage for most first revolution injection opportunities during the time of the lunar month when the injection would occur in this area. A ship positioned at 47°E; 25°S could provide about the same coverage. Either Tananarive or a ship could provide all the coverage for second and third revolution injection opportunities in this area except for a very small region.

2. For early earth orbital coverage (first four revolutions) Tananarive and a ship located as above appear to be equally effective overall.

3. For long duration earth orbital missions, a ship could be optimally located so that it would provide better overall coverage than a fixed ground station at Tananarive.

4. A station equipped with a Comsat terminal would have an advantage in communicating with MCC-H. Three Apollo tracking ships are being equipped with Comsat terminals.

J. P. Maloy

J. P. Maloy

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Attachments
Figures 1-7
Tables I & II

TABLE I

COMPARISON OF TANANARIVE AND INJECTION SHIP ORBITAL COVERAGE (MINUTES)

(105 nm altitude; 0° elevation)

| AZIMUTH | REVOLUTION 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|
| | TAN | SHIP | TAN | SHIP | TAN | SHIP | TAN | SHIP |
| 72° | 5.1 | -- | 7.3 | 7.0 | 5.2 | 7.0 | --- | 6.1 |
| 75 | 6.0 | 2.5 | 7.2 | 7.1 | 5.2 | 7.0 | 2.9 | 6.4 |
| 80 | 6.9 | 5.1 | 7.0 | 7.5 | 5.3 | 7.1 | 4.7 | 6.9 |
| 85 | 7.3 | 6.4 | 6.6 | 7.3 | 5.3 | 7.1 | 5.8 | 7.2 |
| 90 | 7.3 | 7.1 | 6.1 | 7.3 | 5.4 | 7.1 | 6.5 | 7.3 |
| 95 | 6.8 | 7.3 | 5.4 | 7.1 | 5.6 | 7.2 | 7.0 | 7.3 |
| 100 | 5.8 | 7.2 | 4.5 | 6.9 | 5.8 | 7.2 | 7.2 | 7.1 |
| 105 | 3.9 | 6.7 | 3.3 | 6.5 | 5.9 | 7.2 | 7.3 | 6.8 |
| 108 | 1.1 | 6.1 | 2.1 | 6.2 | 6.0 | 7.2 | 7.2 | 6.5 |

TABLE II

COMPARISON OF COVERAGE GAPS WITH TANANARIVE OR SHIP (47°E; 25°S)
(MINUTES)

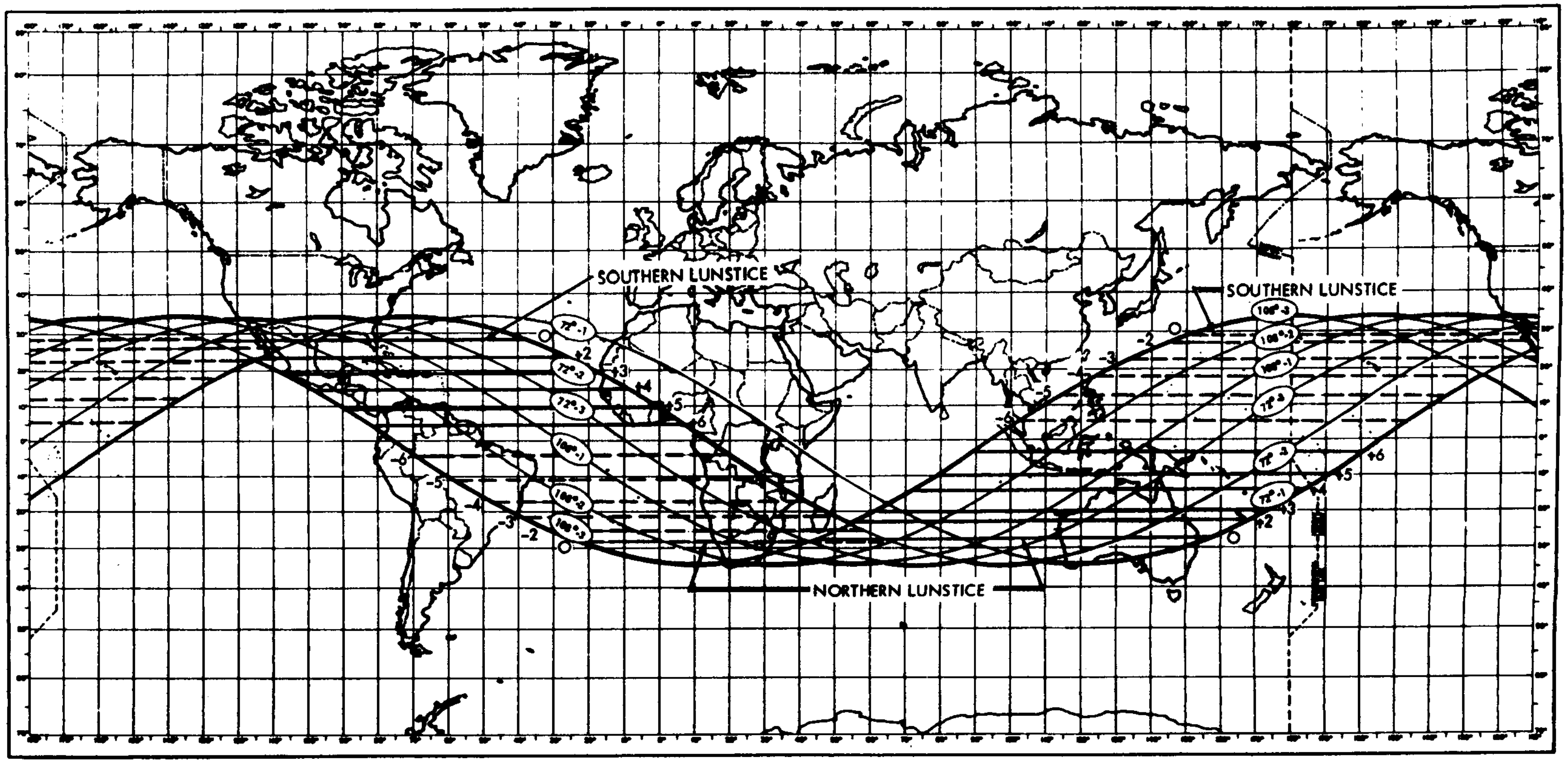
(105 nm altitude; 0° elevation)

| AZIMUTH | REVOLUTION 1 | | | | 2 | | | | 3 | | | | 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TAN | | SHIP | | TAN | | SHIP | | TAN | | SHIP | | TAN | | SHIP | |
| | a* | b* | a | b | a | b | a | b | a | b | a | b | a | b | a | b |
| 72° | 13.7 | 9.7 | 28.5 | 28.5 | 13.0 | 9.2 | 13.8 | 8.7 | 10.0 | 9.7 | 9.4 | 8.4 | 24.2 | 24.2 | 9.4 | 8.9 |
| 75 | 13.2 | 6.0 | 15.7 | 10.2 | 13.7 | 9.0 | 14.3 | 8.5 | 9.6 | 9.5 | 9.0 | 8.4 | 11.1 | 10.8 | 9.3 | 9.2 |
| 80 | 12.9 | 8.8 | 14.4 | 9.1 | 19.4 | 18.9 | 19.5 | 8.3 | 9.4 | 9.5 | 8.7 | 8.4 | 10.8 | 20.6 | 8.7 | 19.7 |
| 85 | 13.5 | 7.3 | 14.5 | 8.5 | 9.5 | 8.9 | 9.5 | 8.3 | 9.5 | 9.8 | 8.7 | 8.9 | 11.1 | 19.8 | 10.1 | 19.5 |
| 90 | 16.1 | 7.3 | 16.6 | 8.3 | 9.1 | 9.1 | 8.7 | 8.4 | 10.0 | 20.4 | 9.0 | 19.7 | 33.4 | 19.7 | 32.5 | 19.8 |
| 95 | 9.9 | 8.8 | 9.9 | 8.2 | 9.4 | 9.7 | 8.6 | 8.8 | 10.9 | 20.0 | 9.8 | 19.5 | 34.5 | 20.0 | 33.7 | 20.5 |
| 100 | 9.3 | 9.2 | 8.8 | 8.3 | 10.3 | 10.6 | 9.1 | 9.5 | 26.4 | 19.9 | 25.3 | 19.7 | 36.7 | 21.5 | 36.0 | 22.2 |
| 105 | 10.0 | 10.0 | 8.7 | 8.6 | 11.9 | 21.2 | 10.1 | 19.9 | 33.9 | 20.5 | 32.8 | 20.5 | 37.9 | 33.1 | 37.3 | 34.2 |
| 108 | 11.4 | 11.2 | 9.1 | 8.8 | 13.8 | 21.6 | 11.4 | 19.9 | 34.4 | 21.6 | 40.3 | 21.7 | 46.8 | 33.2 | 46.3 | 34.4 |

*a - Gap in minutes between drop out of previous station and Tananarive or ship pick-up.

b - Gap in minutes between drop out of Tananarive or ship and pick-up of following station.

When only one figure appears across the a and b columns, Tananarive or the ship has no contact on that revolution and the figure represents gap between the last station contact and the following one.




——— DAYS BEFORE NORTHERN OR SOUTHERN LUNSTICE

– – – – – DAYS AFTER NORTHERN OR SOUTHERN LUNSTICE

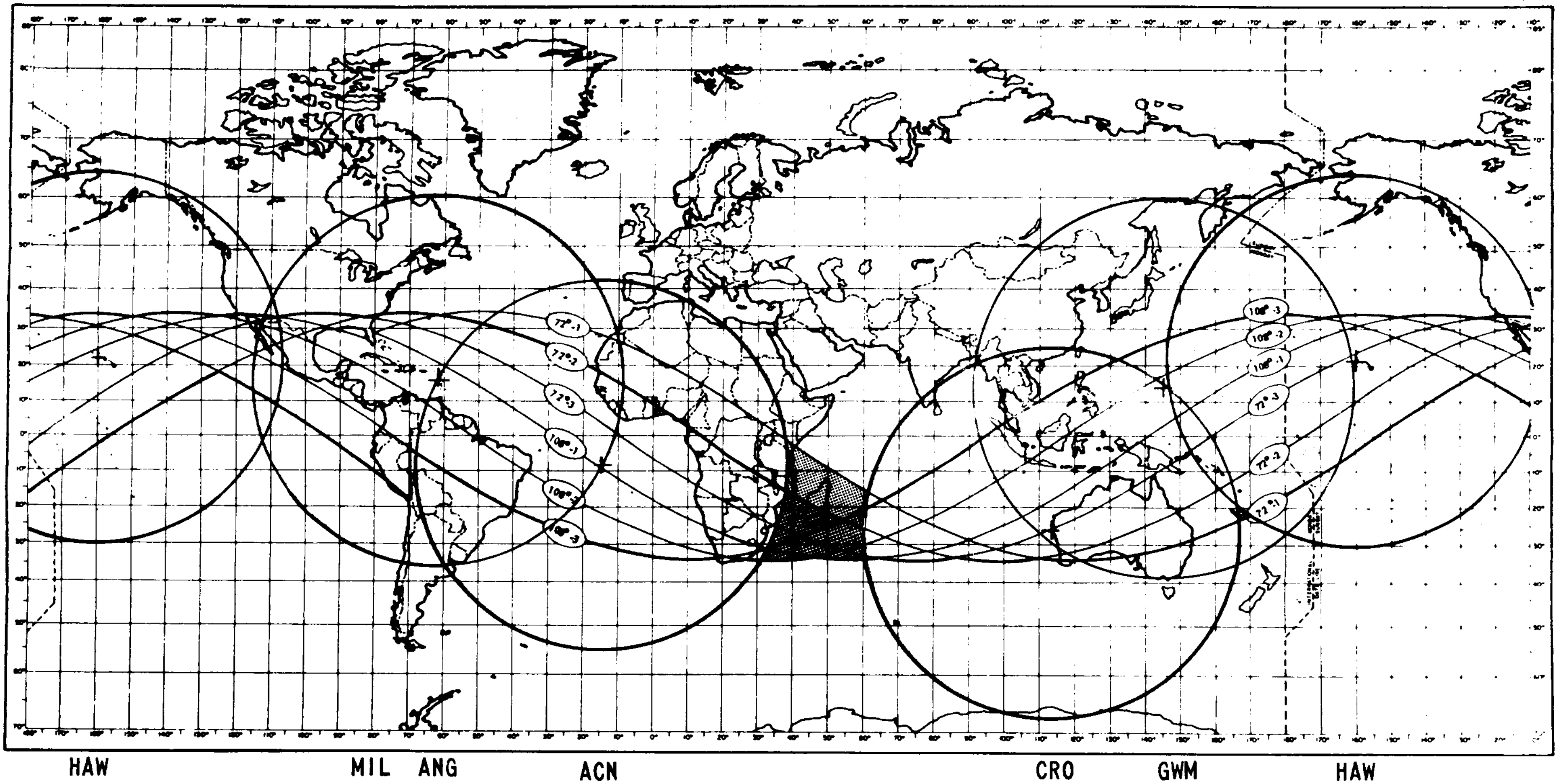
NOTE: LOCI SHOWN ARE FOR SMALL DIHEDRAL ANGLE BETWEEN LUNAR ORBITAL PLANE AND TRANS LUNAR TRAJECTORY PLANE. FOR LARGE DIHEDRAL ANGLES USE

– – – – DAYS AFTER LUNSTICE

——— DAYS BEFORE LUNSTICE

FIGURE I - LOCI OF APOLLO INJECTION OPPORTUNITIES FOR DAYS FROM MAXIMUM LUNAR DECLINATION

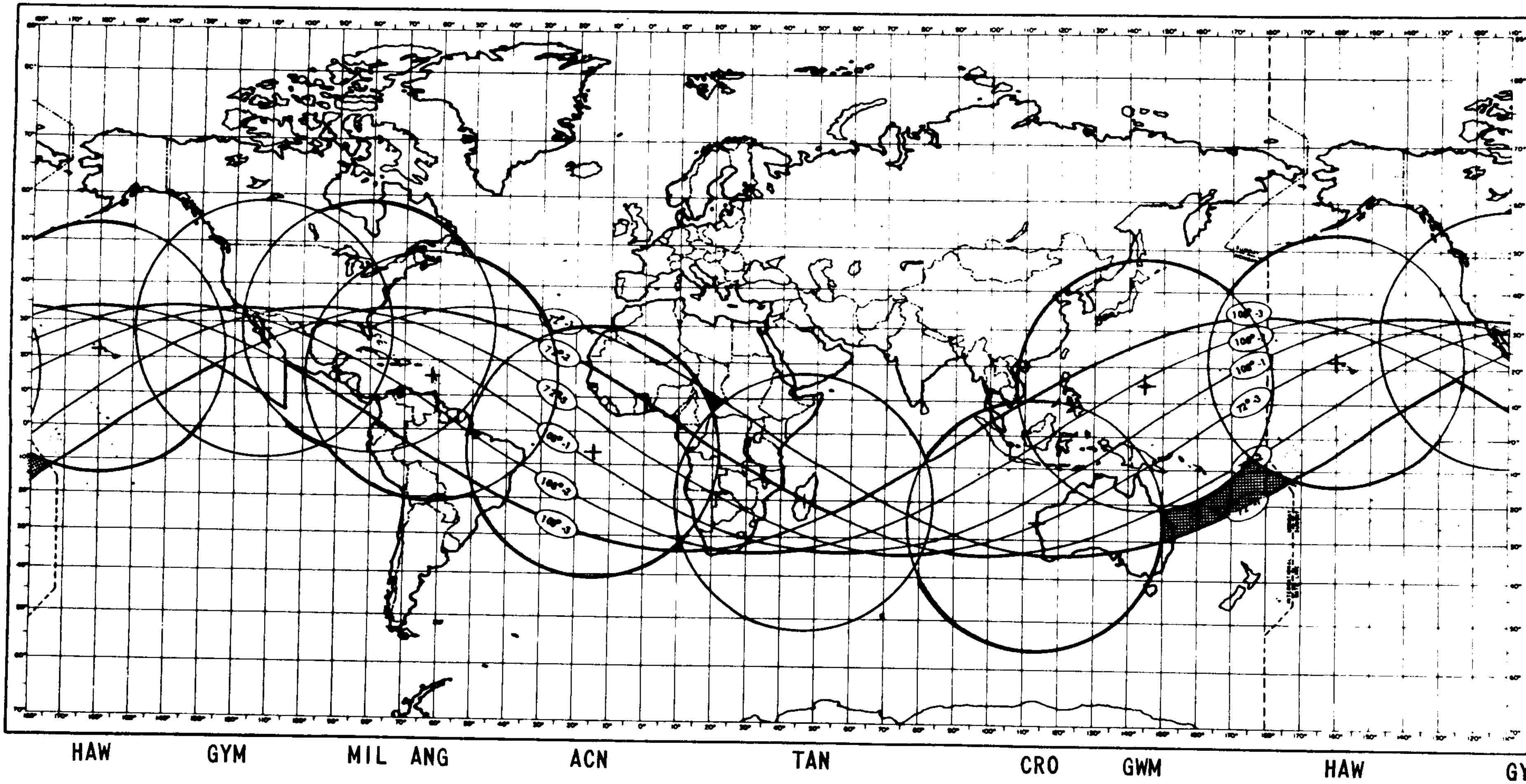
FROM: "A STUDY OF INSTRUMENTATION SHIP REQUIREMENTS FOR THE APOLLO PROGRAM" DATED SEPT. 14, 1963, BY BELLCOMM, INC.




Alt. = 3000 n.m.  Max. Slant Range = 5100 n.m.  Elevation = 5°

FIGURE 2 - COVERAGE FOR 21 MINUTES AFTER INJECTION

FROM: "A STUDY OF INSTRUMENTATION SHIP REQUIREMENTS FOR THE APOLLO PROGRAM" DATED SEPT. 14, 1963, BY BELLCOMM, INC. (SLIGHTLY MODIFIED)




Alt. = 1175 n.m.    Max. Slant Range = 2800 n.m.    Elevation = 5°

FIGURE 3 - COVERAGE FOR 10 MINUTES AFTER INJECTION

FROM: "STUDY OF INSTRUMENTATION SHIP REQUIREMENTS FOR THE APOLLO PROGRAM" DATED SEPT. 14, 1963, BY BELLCOMM, INC. (SLIGHTLY MODIFIED)

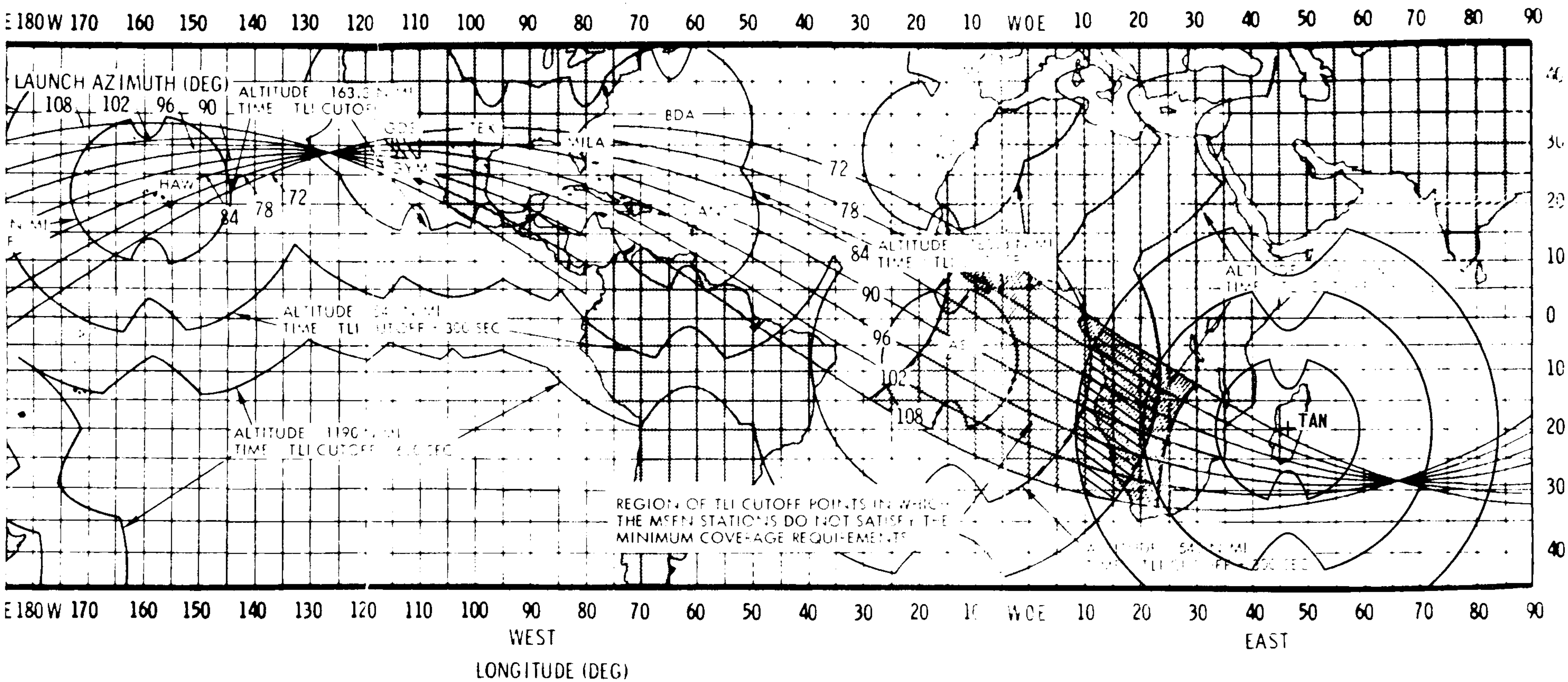



FIGURE 4 - EARTH PARKING ORBIT FOR LAUNCH AZIMUTHS 72 THROUGH 108 DEGREES (SECOND REVOLUTION) AND MSFN VISIBILITY CONTOURS, USB STATIONS, 5-DEGREE MINIMUM ANTENNA ELEVATION ANGLE

FROM: "INJECTION SHIP POSITIONING TECHNIQUE FOR APOLLO LUNAR MISSIONS" DATED JUNE 23, 1967, BY MSC (SLIGHTLY MODIFIED)

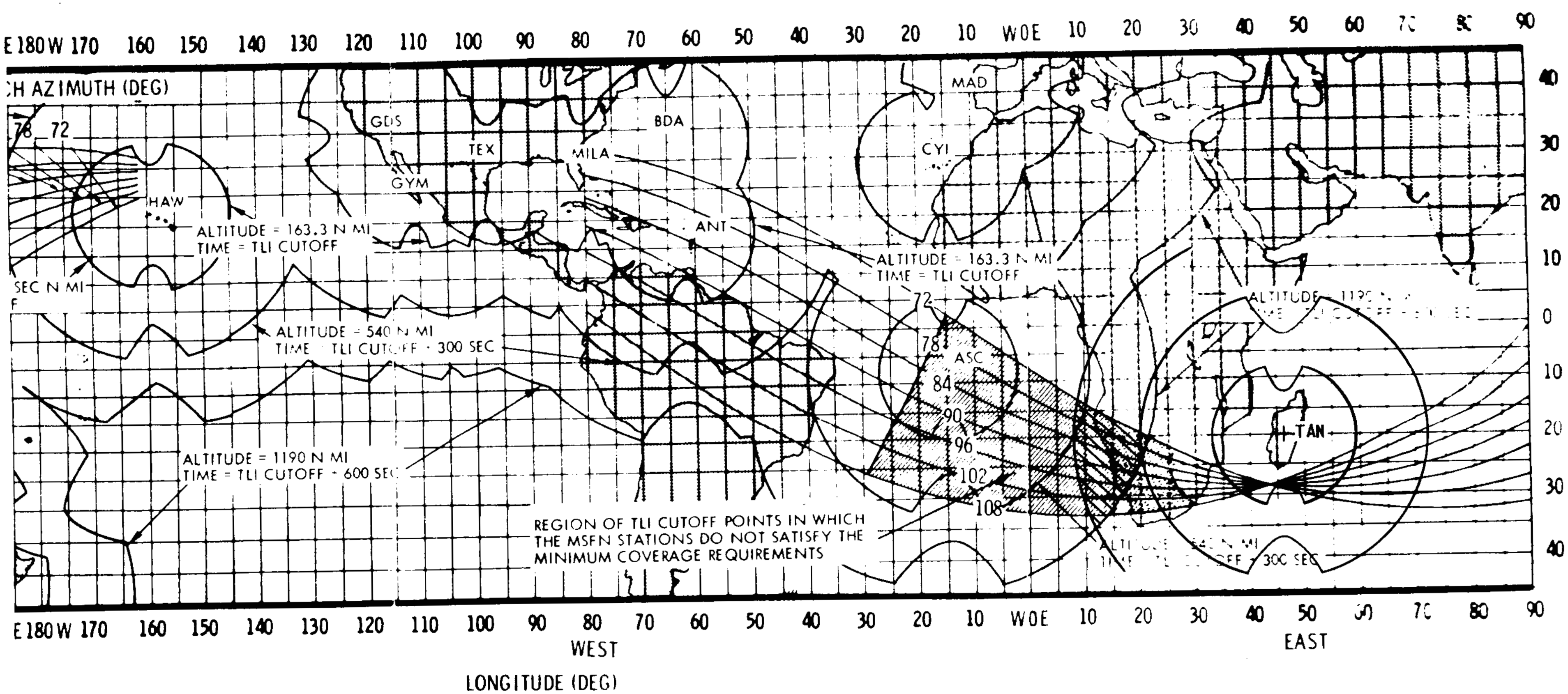
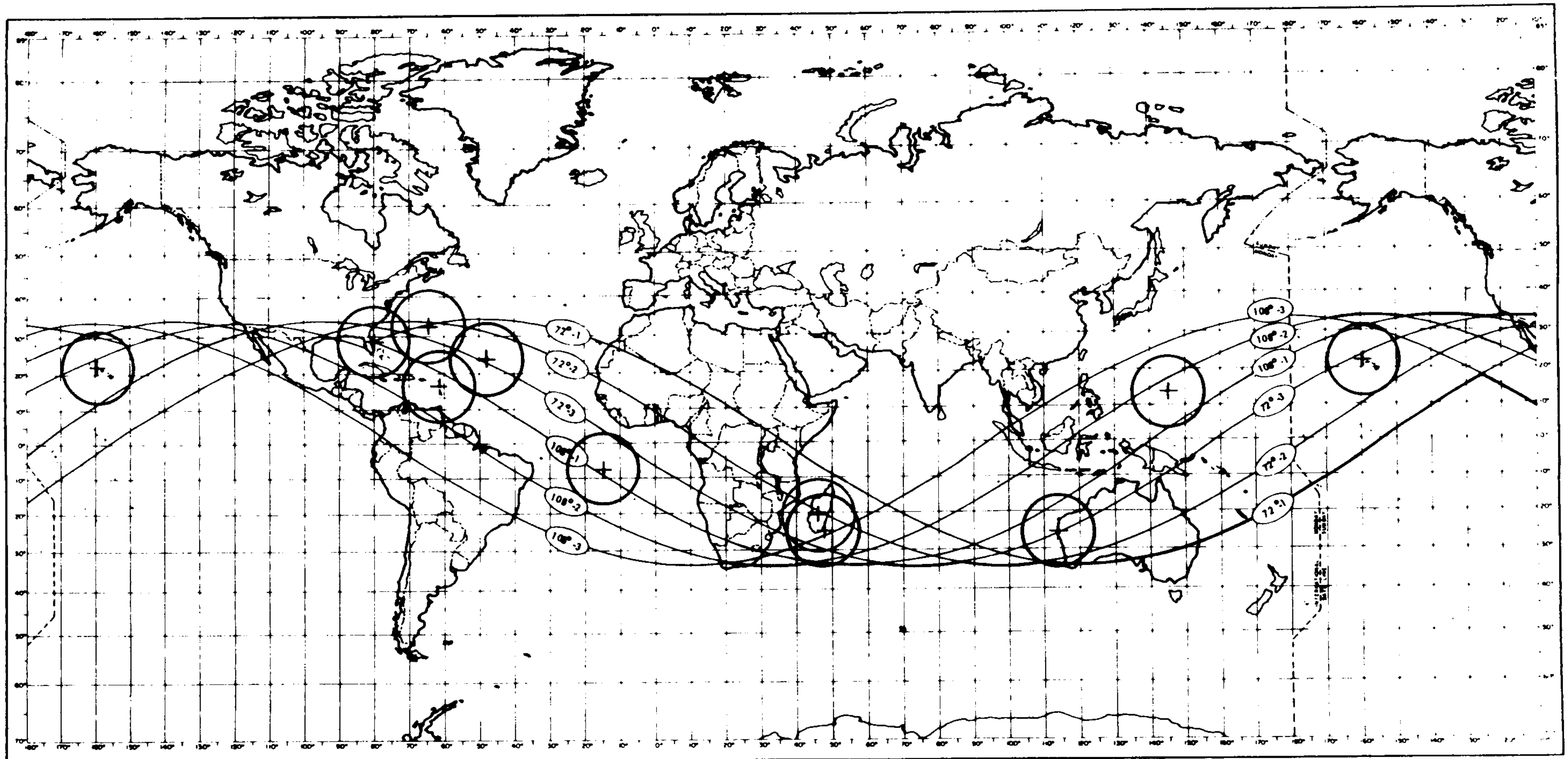



FIGURE 5 - EARTH PARKING ORBIT FOR LAUNCH AZIMUTHS 72 THROUGH 108 DEGREES (THIRD REVOLUTION) AND MSFN VISIBILITY CONTOURS, USB STATIONS, 5-DEGREE MINIMUM ANTENNA ELEVATION ANGLE

FROM: "INJECTION SHIP POSITIONING TECHNIQUE FOR APOLLO LUNAR MISSIONS", DATED JUNE 23, 1967, BY TRW FOR MSC (SLIGHTLY MODIFIED)




HAW GYM MIL BDA INS ACN TAN CRO GWM HAW
ANG SHIP SHIP

Elevation Angle 5° Launch Azimuths 72° To 108°

FIGURE 6 - TRACKING COVERAGE OF FIRST THREE APOLLO PARKING ORBITS

FROM: "A STUDY OF INSTRUMENTATION SHIP REQUIREMENTS FOR THE APOLLO PROGRAM" DATED SEPT. 14, 1963, BY BELLCOMM, INC. (SLIGHTLY MODIFIED)

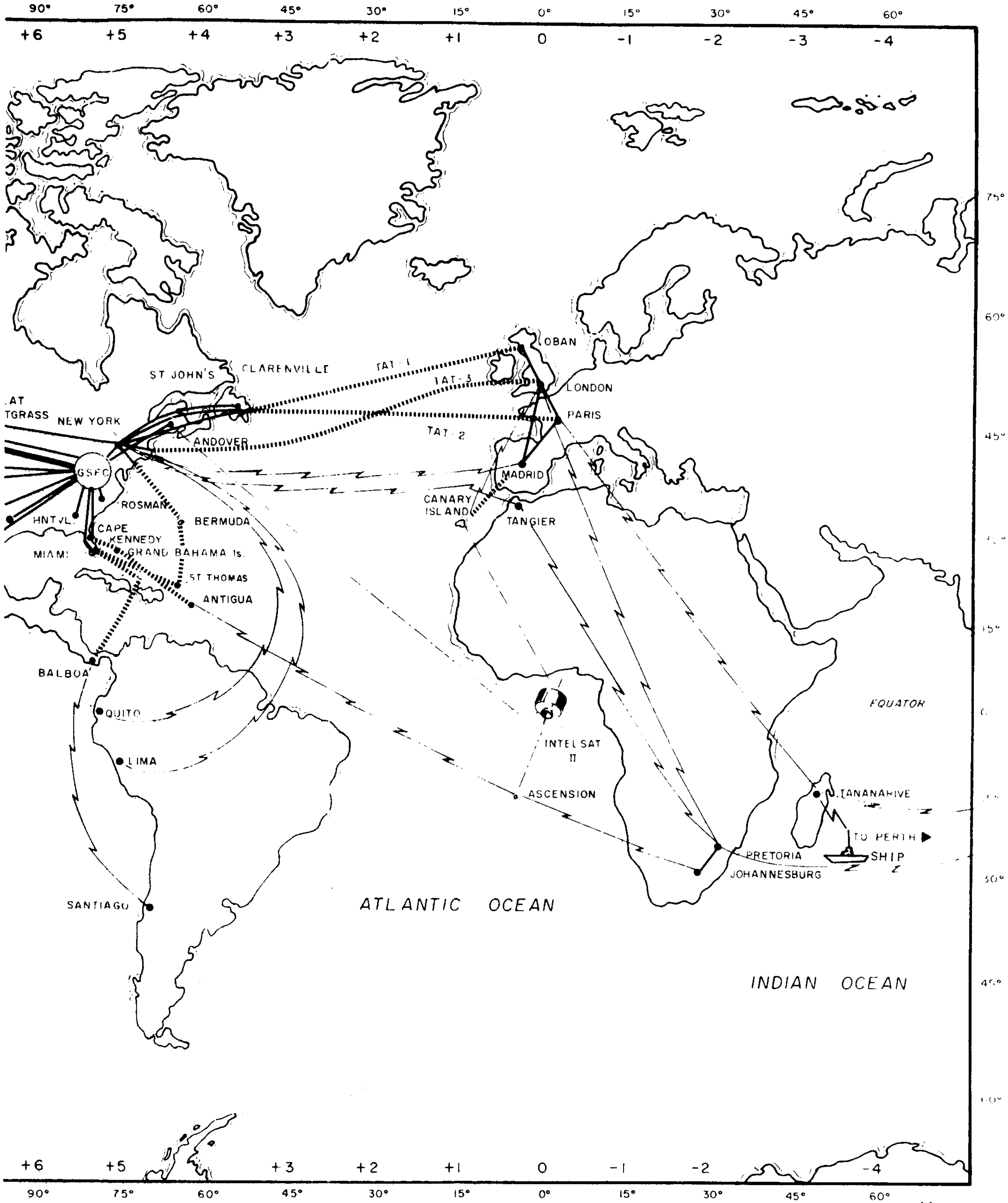



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**FIGURE 7 - COMPARISON OF COMMUNICATION LINKS FROM TANANARIVE AND THE SHIP (47°E; 25°S)**

**FROM: NASCOM NETWORK GRAND COMMUNICATIONS RELIABILITY REPORT FOR JULY 1967, BY GSFC**

**BELLCOMM, INC.**

Subject: Comparison of the Communications and Tracking Coverage Provided by Apollo Injection Ships and Land Stations

From: J. P. Maloy

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